Observation of Quantum Spin Hall States in InAs/GaSb Bilayers under Broken Time-reversal Symmetry

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arXiv 1306.1925

Recommendation and Commentary by Patrick Lee, MIT

The discovery of edge transport channels in a HgTe quantum well by König *et al.*,[1] coming quickly after the theoretical proposal of Bernevig *et al.*,[2] opened up the experimental investigation of the quantum spin Hall insulator, and confirmed the notion of topological insulators advanced by Kane and Mele.[3] The resulting explosion of activities has taken the condensed matter community by storm.[4, 5] It is interesting to note that since the initial discovery, the bulk of the experimental activities has shifted to three dimensional systems such as Bi_2Se_3 and Bi_2Te_3. As far as I am aware, until very recently,[6] all publications on the HgTe quantum well system are based on samples supplied by the Molenkamp group. This is because very few groups possess the expertise to work with this material. If this trend continues, the two dimensional quantum spin Hall effect may be in danger of becoming a historical footnote. It is indeed a welcome development that recent advances on a new system assures that this will not happen.

The new system is the inverted electron-hole (InAs/GaSb) bilayer. The theoretical proposal also came from the Stanford group[7] and has been realized by the group of R.R. Du[8, 9] and others.[10] The idea is that the conduction band of InAs is some 150 meV lower than the valence band of GaSb. In an InAs/GaSb quantum well, the position of the electron and hole subbands can be controlled by varying the thickness of the InAs and GaSb layers. For sufficiently wide wells, band inversion needed for a topologically nontrivial state can be achieved. Due to tunnelling across the interface, the hybridization of the electron and hole states opens a mini-gap of 40–60 K and helical edge states (counter-propagating modes which carry opposite spins) are expected to exist in this gap. In their first paper, Knez et al.[8] found evidence for these edge modes by conductance measurements, but the expected conductance quantization was not very precise, presumably due to the presence of disorder induced states inside the mini-gap.

In the recent paper, Du *et al.* took the clever step of introducing a very small amount of Si dopant ($\sim 10^{11}\mathrm{cm}^{-2}$) at the interface, which serves as donors in InAs and acceptors in

GaSb. The donors and acceptors localize the electrons and holes, creating a mobility gap estimated to be 26 K inside the mini-gap. Now the transport is entirely dominated by the edge states. As a function of gate voltage, wide conductance plateaus which are quantized to within 1% of the expected integer multiples of e^2/h are observed. These are significant improvements over what was observed in HgTe quantum wells. (See the April 2013 comment by Jason Alicea on this issue.) Du *et al.* also investigated the effect of a magnetic field in all three orientations. The plateaus are robust to a surprising large parallel field which breaks time reversal symmetry. This remains to be understood.

The advantage of the InAs/GaSb system is that the technology is more accessible and we can expect further progress in 2d topological insulators as more groups get involved. The single channel edge state has intrinsic advantages over the 3d system if a single channel quantum wire limit is desirable. For example, this may be an excellent platform to create 1d wires proximity coupled to superconductors, with the goal to create Majorana bound states at its ends, as proposed by Fu and Kane.[11] Indeed, concrete proposals towards this end are beginning to appear in the literature.[12] We can surely expect a lot more exciting developments in this direction in the near future.

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